CLAIMS

We claim:

1	1.	A system	comprising:

- 2 a wavelet-based image processing path to enhance an input image in
- 3 a wavelet domain; and
- 4 a print engine coupled to the processing path.
- 1 2. The system defined in Claim 1 wherein the image processing
- 2 path comprises:
- 3 a forward wavelet transform;
- 4 one or more wavelet-based processing blocks; and
- 5 an inverse wavelet transform.
- 1 3. The system defined in Claim 2 wherein the forward wavelet
- 2 transform comprises a critically sampled wavelet transform.
- 1 4. The system defined in Claim 2 wherein the forward wavelet
- 2 transform comprises an overcomplete wavelet transform.

- 1 5. The system defined in Claim 2 wherein the forward wavelet
- 2 transform comprises a Haar wavelet transform.
- 1 6. A system defined in Claim 2 wherein the forward wavelet
- 2 transform comprises a 5,3 wavelet transform.
- 1 7. A system defined in Claim 2 wherein the forward wavelet
- 2 transform comprises a 2,6 wavelet transform.
- 1 8. A system defined in Claim 2 wherein the forward wavelet
- 2 transform comprises a complex wavelet transform.
- 1 9. A system defined in Claim 2 wherein the forward wavelet
- 2 transform comprises a limited redundancy wavelet transform.
- 1 10. The system defined in Claim 1 wherein the image processing
- 2 path comprises:
- 3 a forward wavelet transform;

- a denoising processing block coupled to the forward wavelet
 transform to perform denoising based on at least one given threshold; and
 an inverse wavelet transform.
- The system defined in Claim 10 wherein the denoising
 processing block sets coefficients below the at least one given threshold to a
- 3 predetermined value less than the threshold.
- 1 12. The system defined in Claim 11 wherein the at least one given 2 threshold is calculated based on the presence of additive Gaussian white 3 noise in an image.
- 1 13. The system defined in Claim 11 wherein the at least one given
 2 threshold is calculated from a series of test images.
- 1 14. The system defined in Claim 11 wherein the at least one given
- 2 threshold comprises different thresholds applied to different levels of
- 3 decomposition.

- 1 15. The system defined in Claim 11 wherein the at least on given
- 2 threshold comprises different thresholds are applied to different bands.
- 1 16. The system defined in Claim 11 wherein the at least one given
- 2 threshold is set manually.
- 1 17. The system defined in Claim 11 wherein the at least one given
- 2 threshold is set based on the standard deviation or medium of absolute
- 3 values of coefficients in the region.
- 1 18. The system defined in Claim 17 wherein the at least one given
- 2 threshold is set on the standard deviation of HH coefficients at level one.
- 1 19. The system defined in Claim 11 wherein the at least one given
- 2 threshold is set in the standard deviation or medium of absolute values of
- 3 HH coefficients at each level.
- 1 20. The system defined in Claim 11 wherein the at least one given
- 2 threshold is set based on the standard deviation or medium of absolute

- 3 values of H/HL/HH coefficients at a first level at a particular level to create
- 4 a band dependent threshold.
- 1 21. The system defined in Claim 11 wherein the at least one given
- 2 threshold is set based on a standard deviation or medium of absolute values
- 3 of LH/HL/HH coefficients at each level.
- 1 22. The system defined in Claim 11 wherein the at least one given
- 2 threshold is set manually using controls on a user interface.
- 1 23. The system defined in Claim 11 wherein the at least one given
- 2 threshold is set by computing local variances/mediums of coefficients in
- 3 between a band.
- 1 24. The system defined in Claim 11 wherein the at least one given
- 2 threshold is set using a classifier.

- 1 25. The system defined in Claim 11 wherein the denoising
- 2 processing block sets all coefficients below the at least one given threshold to
- 3 zero.
- 1 26. The system defined in Claim 1 wherein the image processing
- 2 path comprises:
- a forward wavelet transform;
- 4 a sharpening or smoothing processing block coupled to the forward
- 5 wavelet transform to sharpen or smooth coefficients based on the magnitude
- 6 of individual coefficients; and
- 7 an inverse wavelet transform.
- 1 27. The system defined in Claim 26 wherein the sharpening or
- 2 smoothing processing block multiplies wavelet coefficients with a scale
- 3 dependent factor.
- 1 28. The system defined in Claim 27 wherein the scale-dependent
- 2 factor comprises:

$$\mu_{j} = R \cdot 2^{\alpha j}$$

- 4 where R is a renormalization factor and α is the parameter that determines
- 5 the degree of sharpening or smoothing.
- 1 29. The system defined in Claim 26 wherein the sharpening or
- 2 smoothing processing block normalizes coefficients after sharpening or
- 3 smoothing.
- 1 30. The system defined in Claim 28 wherein the sharpening or
- 2 smoothing processing block uses a scale dependent factor that is selected to
- 3 include normalization.
- 1 31. The system defined in Claim 1 wherein the image processing
- 2 path comprises a linear interpolation filter that is applied to wavelet
- 3 coefficients.
- 1 32. The system defined in Claim 31 wherein the image processing
- 2 path comprises:
- 3 an inverse wavelet transform to inverse transform coefficients down
- 4 to a predetermined level;

- a downsampling block coupled to the inverse wavelet transform to
 downsample wavelet coefficients.
- 1 33. The system defined in Claim 32 wherein the downsampling
- 2 block performs either a deterministic or random downsampling based on
- 3 coefficient size at the predetermined level.
- 1 34. The system defined in Claim 32 wherein the downsampling
- 2 block uses at least one interpolation filter based on a value of a coefficient
- 3 with respect to a predetermined threshold.
- 1 35. The system defined in Claim 34 wherein the at least one
- 2 interpolation filter comprises a Key's filter.
- 1 36. The system defined in Claim 34 wherein the downsampling
- 2 processing block applies a smoothing filter to wavelet coefficients that are
- 3 smaller than a first threshold and a sharpening filter to wavelet coefficients
- 4 that are larger than a second threshold.

1	37. The system defined in Claim 1 wherein the image processing					
2	path comprises:					
3	a forward wavelet transform;					
4	a denoising processing block coupled to the forward wavelet					
5	transform to perform denoising based on a given threshold;					
6	a sharpening or smoothing processing block coupled to the denoising					
7	processing block to sharpen or smooth coefficients based on the magnitude					
8	of individual coefficients;					
9	an inverse wavelet transform coupled to the sharpening or smoothing					
10	processing block; and					
11	a downsampling block coupled to the inverse wavelet transform to					
12	downsample wavelet coefficients.					

- 1 38. The system defined in Claim 1 further comprising an input 2 operable to receive the input image from an external source and a scanner 3 for generating the input image, wherein the input and the scanner are 4 coupled to the image processing path.
- 1 39. A method comprising:

- processing an input image by enhancing the input image, including
 applying a forward wavelet transorm to create a plurality of coefficients and
 filtering coefficients with a coefficient domain operator in a wavelet domain;
 and
 outputting a processed image.
- 40. The method defined in Claim 39 further comprising:
 applying one or more wavelet-based processing blocks to coefficients
 resulting from applying the forward wavelet transform; and
 applying an inverse wavelet transform.
- The method defined in Claim 40 wherein the forward wavelet
 transform comprises a critically sampled wavelet transform.
- 42. The method defined in Claim 40 wherein the forward wavelet
 transform comprises an overcomplete wavelet transform.
- 43. The method defined in Claim 40 wherein the forward wavelet
 transform comprises a Haar wavelet transform.

- 1 44. A system defined in Claim 40 wherein the forward wavelet
- 2 transform comprises a 5,3 wavelet transform.
- 1 45. A system defined in Claim 40 wherein the forward wavelet
- 2 transform comprises a 2,6 wavelet transform.
- 1 46. A system defined in Claim 40 wherein the forward wavelet
- 2 transform comprises a complex wavelet transform.
- 1 47. A system defined in Claim 40 wherein the forward wavelet
- 2 transform comprises a limited redundancy wavelet transform.
- 1 48. The method defined in Claim 39 further comprising:
- 2 performing denoising on the plurality of coefficients based on a given
- 3 threshold; and
- 4 applying an inverse wavelet transform on the plurality of coefficients
- 5 after denoising.

- 1 49. The method defined in Claim 1 wherein performing denoising
- 2 comprises setting coefficients below the at least one given threshold to a
- 3 predetermined value.
- 1 50. The system defined in Claim 49 wherein the at least one given
- 2 threshold is calculated based on the presence of additive Gaussian white
- 3 noise in an image.
- 1 51. The system defined in Claim 49 wherein the at least one given
- 2 threshold is calculated from a series of test images.
- 1 52. The system defined in Claim 49 wherein the at least one given
- 2 threshold comprises different thresholds are applied to different levels of
- 3 decomposition.
- 1 53. The system defined in Claim 49 wherein the at least one given
- 2 threshold comprises different thresholds are applied to different bands.

- 54. The system defined in Claim 49 wherein the at least one giventhreshold is set manually.
- 1 55. The system defined in Claim 49 wherein the at least one given
- 2 threshold is set based on the standard deviation or medium of absolute
- 3 values of coefficients in the region.
- 1 56. The system defined in Claim 55 wherein the at least one given
- 2 threshold is set on the standard deviation of HH coefficients at level one.
- 1 57. The system defined in Claim 49 wherein the at least one given
- 2 threshold is set in the standard deviation or medium of absolute values of
- 3 HH coefficients at each level.
- 1 58. The system defined in Claim 49 wherein the at least one given
- 2 threshold is set based on the standard deviation or medium of absolute
- 3 values of H/HL/HH coefficients at a first level at a particular level to create
- 4 a band dependent threshold.

- 1 59. The system defined in Claim 49 wherein the at least one given
- 2 threshold is set based on a standard deviation or medium of absolute values
- 3 of LH/HL/HH coefficients at each level.
- 1 60. The system defined in Claim 49 wherein the at least one given
- 2 threshold is set manually using controls on a user interface.
- 1 61. The system defined in Claim 49 wherein the at least one given
- 2 threshold is set by computing local variances/mediums of coefficients in
- 3 between a band.
- 1 62. The system defined in Claim 49 wherein the at least one given
- 2 threshold is set using a classifier.
- 1 63. The method defined in Claim 49 wherein performing
- 2 denoising comprises setting all coefficients below the at least one given
- 3 threshold to zero.
- 1 64.. The method defined in Claim 39 further comprising:

- 2 sharpening or smoothing coefficients based on the magnitude of
- 3 individual coefficients; and
- 4 applying an inverse wavelet transform on the plurality of coefficients
- 5 after sharpening or smoothing.
- 1 65. The method defined in Claim 64 wherein sharpening or
- 2 smoothing comprises multiplying wavelet coefficients with a scale
- 3 dependent factor.
- 1 66. The method defined in Claim 65 wherein the scale-dependent
- 2 factor comprises:

$$\mu_{_{j}}=R\cdot 2^{\alpha j}$$

- 4 where R is a renormalization factor and α is the parameter that determines
- 5 the degree of sharpening or smoothing.
- 1 67. The method defined in Claim 64 wherein sharpening or
- 2 smoothing comprises normalizing coefficients.

- 68. The method defined in Claim 39 further comprising applying a
 linear interpolation filter to wavelet coefficients.
- 1 69. The method defined in Claim 39 further comprising:
- 2 applying an inverse wavelet transform to inverse transform
- 3 coefficients down to a predetermined level; and
- 4 downsampling wavelet coefficients.
- 1 70. The method defined in Claim 69 wherein downsampling the
- 2 wavelet coefficients comprises performing either a deterministic or random
- 3 sampling based on coefficient size at the predetermined level.
- 1 71. The method defined in Claim 69 wherein downsampling
- 2 wavelet coefficients comprises using at least one interpolation filter based on
- 3 a value of a coefficient with respect to a predetermined threshold.
- 1 72. The method defined in Claim 71 wherein the at least one
- 2 interpolation filter comprises a Key's filter.

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1	73. The method defined in Claim 69 wherein downsampling					
2	comprises applying a smoothing filter to wavelet coefficients that are smaller					
3	than a first threshold and a sharpening filter to wavelet coefficients that are					
4	larger than a second threshold.					
1	74. The method defined in Claim 39 further comprising:					
2	performing denoising on coefficients of the plurality of coefficients					
3	based on a given threshold;					
4	sharpening or smoothing coefficients of the plurality of coefficients					
5	based on the magnitude of individual coefficients; and					
6	applying an inverse wavelet transform to the plurality of coefficients					
7	and downsampling wavelet coefficients.					
1	75. A system comprising:					
2	an image enhancement subsystem having a classifier to control one or					
3	more of the following: denoising, sharpening, smoothing, halftoning, under					
4	color removal; and					

an output coupled to the image enhancement subsystem.

- 1 76. The system defined in Claim 75 wherein the image
- 2 enhancement subsystem operates, at least in part, in the wavelet domain.
- 1 77. A method comprising:
- 2 computing a classifier;
- 3 selecting different denoising thresholds for halftone and text regions
- 4 of an image based on the classifier.
- 1 78. The method defined in Claim 77 wherein computing the
- 2 classifier comprises computing the classifier from wavelet coefficients.
- 1 79. The method defined in Claim 78 wherein computing a
- 2 classifier comprises computing a standard deviation of wavelet coefficients
- 3 in different bands.
- 1 80. The method defined in Claim 78 wherein computing a
- 2 classifier comprises computing a standard deviation of wavelet coefficients
- 3 in different decomposition levels.

applying different denoising and sharpening/smoothing parameters

to wavelet coefficients in text halftone and background regions of image

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data.

1	81.	The method defined in Claim 78 wherein computing a				
2	classifier comprises computing a standard deviation of wavelet coefficients					
3	across different bands.					
1	82.	The method defined in Claim 78 wherein computing a				
2	classifier comprises computing a first absolute movement.					
1	83.	The method defined in Claim 78 further comprising:				
2	comp	outing a standard deviation of wavelet coefficients; and				

- 1 84. A method comprising:
- 2 applying a forward wavelet transform to image data:
- 3 performing denoising by thresholding coefficients generated by
- 4 applying the forward wavelet transform;
- 5 rescaling coefficients by filtering coefficients after thresholding.

- 1 85. The method defined in Claim 84 further comprising sampling
- 2 the wavelet coefficients.
- 1 86. The method defined in Claim 84 further comprising applying
- 2 an inverse wavelet transform on filtered coefficients.
- 1 87. The method defined in Claim 84 wherein scaling coefficients
- 2 comprises performing sharpening or smoothing by multiplying coefficients
- 3 with a level dependent parameter.
- 1 88. The method defined in Claim 87 wherein high frequency bands
- 2 are multiplied with a larger factor than low frequency bands to perform
- 3 sharpening.
- 1 89. The method defined in Claim 87 wherein low frequency bands
- 2 are multiplied by a larger factor than the high frequency bands to perform
- 3 smoothing.

- 1 90. The method defined in Claim 88 wherein rescaling coefficients
- 2 comprises filtering LL band coefficients with a high pass filter.
- 1 91. The method defined in Claim 89 wherein rescaling coefficients
- 2 comprises filtering LL band coefficients with a low pass filter.
- 1 92. The method defined in Claim 84 further comprising filtering of
- 2 a subband at a specific level decomposition to modify the subband.
- 1 93. The method defined in Claim 92 further comprising filtering
- 2 the LL component at the largest decomposition level with a sharpening
- 3 filter.
- 1 94. The method defined in Claim 92 further comprising filtering
- 2 the LL component at the largest decomposition level with a smoothing filter.
- 1 95. The method defined in Claim 84 wherein filtering coefficients
- 2 comprises removing periodic patterns in a specific band by applying a filter
- 3 to the specific band.

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notch filter.

- 96. The method defined in Claim 95 wherein the filter comprises a
 band pass filter.
- 1 97. The method defined in Claim 95 wherein the filter comprises a
- 1 98. The method defined in Claim 84 wherein the period is 3.
- 1 99. The method defined in Claim 84 wherein the period is 5.
- 1 100. The method defined in Claim 84 further comprising
- 2 performing halftoning.
- 1 101. The method defined in Claim 100 wherein performing
- 2 halftoning comprises adding white noise with a scaled dependent variance
- 3 to wavelet coefficients.

- 1 102. The method defined in Claim 100 wherein performing
- 2 halftoning comprises adding white noise with a subband dependent
- 3 variance to wavelet coefficients.
- 1 103. The method defined in Claim 84 further comprising
- 2 resampling image data.
- 1 104. The method defined in Claim 103 further comprising
- 2 performing an inverse wavelet transform.
- 1 105. The method defined in Claim 104 wherein performing
- 2 resampling image data and performing inverse wavelet transform are
- 3 performed simultaneously by performing resampling directly on wavelet
- 4 coefficients.
- 1 106. The method defined in Claim 105 wherein the resampling is
- 2 performed using an interpolation filter.

- 1 107. The method defined in Claim 106 wherein the interpolation
- 2 filter comprises a Key's interpolation filter which is implemented on Haar
- 3 wavelet coefficients.
- 1 108. The method defined in Claim 107 wherein performing
- 2 resampling using an interpolation filter comprises computing an
- 3 overcomplete transform and critically sampling coefficients.
- 1 109. The method defined in Claim 107 wherein the Key's
- 2 interpolation filter performs the following procedure on wavelet coefficients:
- 3 $x_{int} = (a_0 + a_1 + a_2 + a_3)s_i^2 + (a_0 + a_1 a_2 a_3)d_i^2 + (a_0 a_1)d_i^3 + (a_2 a_3)d_{i+1}^3$.
- 1 110. A method comprising:
- 2 applying a forward wavelet transform to image data;
- 3 performing a filtering operation on coefficients with a coefficient
- 4 domain operator; and
- 5 applying an inverse wavelet transform to coefficients after filtering.

- 1 111. The method defined in Claim 110 wherein performing a
- 2 filtering operation comprises filtering a subband at a specific level
- 3 decomposition to modify the single subband.
- 1 112. The method defined in Claim 111 wherein performing a
- 2 filtering operation comprises filtering the LL component at the largest
- 3 decomposition level with a sharpening filter.
- 1 113. The method defined in Claim 111 wherein performing a
- 2 filtering operation comprises filtering the LL component at the largest
- 3 decomposition level with a smoothing filter.
- 1 114. The method defined in Claim 110 wherein performing a
- 2 filtering operation comprises removing periodic patterns in a specific band
- 3 by applying a filter to the specific band.
- 1 115. The method defined in Claim 114 wherein the filter comprises
- 2 a band pass filter.

- 1 116. The method defined in Claim 114 wherein the filter comprises
- 2 a notch filter.
- 1 117. The method defined in Claim 110 wherein the period is 3.
- 1 118. The method defined in Claim 110 wherein the period is 5.
- 1 119. A copier having a wavelet-based image processing path for
- 2 enhancing image data.
- 1 120. A printer having a wavelet-based image processing path for
- 2 enhancing image data.